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# New cars and emissions: Effects of policies, macroeconomic impacts and cities characteristics in Portugal

Daniel Magueta [a], Mara Madaleno [b, *], Marta Ferreira Dias [b], Mónica Meireles [c]

[a] ESTGA – Águeda School of Technology and Management, University of Aveiro, R. Comandante Pinho e Freitas, P.O. Box 473, 3754-909, Águeda, Portugal
[b] GOVCOPP – Research Unit on Governance, Competitiveness and Public Policies, DEGEIT – Department of Economics, Management, Industrial Engineering and Tourism, University of Aveiro, Campus Universitário de Santiago, 3810-193, Aveiro, Portugal
[c] ISCTE Business School - Department of Economics and BRU-IUL, ISCTE-IUL – Lisbon University Institute, Av. das Forças Armadas, 1649-026, Lisboa, Portugal

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ABSTRACT

The Paris Agreement on climate change is the first international climate agreement that extends mitigation obligations to all countries. Accordingly, the EU has already put in place some policy measures to decrease $CO_2$ and GHG emissions from cars, e.g. the obligation of each Member State to provide information on the fuel-efficiency of new passenger cars, namely on fuel consumption and $CO_2$ emissions. In Portugal, in 2013, the transport sector was responsible for 33.3% of energy consumption with the road transport accounting for 95% of this percentage. Furthermore, the transport sector was also responsible for 34.7% of $CO_2$ emissions, a value highly concentrated in the major cities. To improve significant reductions on emissions in the transport sector, the Government has introduced several energy efficiency measures. Although there are many countries that have introduced special programs aimed at increasing vehicle replacement through new low-carbon vehicles purchases, little attention has been paid to their impact on sales and prices. Using a completely unexplored database of sales regarding new cars sold in Portugal during the period of 2002 and 2016 we have explored the evolution of average $CO_2$ emissions and sales considering different types of new cars sold (gasoline, diesel and electrical) in terms of descriptive statistics. We have also applied multiple regression models using macroeconomic variables able to justify changes in terms of both sales and emissions. Results demonstrate that including macroeconomic effects, household characteristics and city specificities are important for both emissions and sales explanatory behaviour that allow inferring how policy makers should redirect attention when formulating new policies regarding environmental performance.

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## 1. Introduction

The Paris Agreement (COP21) on climate change is the first international climate agreement that extends mitigation obligations to all countries, both developed and developing. Since the energy and the transport sector account together for about two-thirds of the global GHG, mitigation actions in these sectors are crucial to achieve the global climate goals by decarbonizing the industrialised countries and shifting developing countries into a low-carbon development path (IEA, 2016a). Through this Agreement, all countries have expressed their commitment to limit the increase in the global average temperature below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C (UNFCCC, 2016). The transport sector is the second largest emitter of $CO_2$ worldwide. In 2014, it contributed to 23% of global $CO_2$ emissions while the electricity and heat generation accounted for 42% (IEA, 2016a). In the European Union (EU), the transport sector is responsible for about 21% of the greenhouse gas (GHG) emissions, with 12% (more than one half) of the emissions produced by passenger cars. Currently, 98% of the transport sector in the EU depends on fossil fuels (EU, 2009).

As a result, the EU has already put in place some policy measures to decrease GHG emissions from cars. To facilitate an informed choice, the EU Directive 1999/94/EC on labelling obliges Member States to provide information on the fuel-efficiency of new

* Corresponding author.
*E-mail addresses:* dmagueta@ua.pt (D. Magueta), maramadaleno@ua.pt (M. Madaleno), mfdias@ua.pt (M. Ferreira Dias), monica.meireles@iscte-iul.pt (M. Meireles).

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passenger cars, namely on fuel consumption and $CO_2$ emissions. The EU Directive 2009/33/EC on the promotion of clean and energy efficient road transport vehicles promotes a broader market penetration of environmentally friendly vehicles to both decarbonize the transport sector and to reduce oil dependency. Accordingly, the EU Directive 2009/443/EC mandates car manufacturers to decrease the average $CO_2$ emissions of new passenger cars sold to a maximum of 130 $gCO_2$/km in 2015 and 95 $gCO_2$/km in 2020/1 by labelling every car (Fridstrom and Ostli, 2017). To meet the targets, automobile manufacturers are proposing a wider range of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs – combines an electric engine and an internal combustion engine).

Electric vehicles (EVs) remain considerably more expensive to buy than a comparable gasoline or diesel car. To overcome the cost disadvantage of these eco-friendly vehicles and get appropriate payback periods, most EU member states have introduced policy measures. Nevertheless, in the majority of Member States, EV sales remain negligible.

Currently, the policy instruments aiming at inducing consumers to adopt innovative technologies, to aid decreasing environmental damages are the initial registration or purchase taxes, the circulation or motor taxes and the fuel taxes. The former is an up-front cost that, if differentiated according to the $CO_2$ emissions of the vehicles, may have a strong impact on leading buying decisions to low carbon vehicles. The exemption or reduction of this tax increases the affordability of electric vehicles by reducing the marginal capital costs. Consumers often mention this cost as one of the main barriers for cars purchasing. In their decisions, consumers usually place much more attention to the up-front purchase price than to annual or monthly charges (Gass et al., 2014). The circulation tax is associated to the engine power, cylinder capacity or fuel consumption. Its impact in the electric vehicles price is lower since their payment is in a monthly or annually basis. As regards the fuel taxes, they restrict the energy consumption in road transport and they incentivize not only consumers to buy cars that are more efficient but also to help those changing driving patterns. The automobile fuel economy is crucial for energy security, especially due to the increasing volatility in fuel prices and the continuous geopolitical instability in the major oil producing regions.

In France, for instance, the Government has implemented a feebate system, whereby new passenger cars emitting less than 130 $gCO_2$/km receive a subsidy (bonus), whereas those emitting more than 160 $gCO_2$/km pay a purchase tax (malus). The subsidy (financial rebate) varies between 200 and 1000 euros, while the tax varies from 200 to 2600 euros (D'Haultfoeuille et al., 2016).

In Spain, for instance, the Government has implemented the Plan 2000E, which is very similar to the Portuguese one. It subsidizes the replacement of an old car by a new one, more efficient. This plan aimed at providing a total subsidy of €2,000, is co-financed by the National Government and the Autonomous Communities (who contributed with €500 each) and manufacturers (who contributed with €1000). With this plan, consumers could benefit from this subsidy by replacing a vehicle, with at least 10 years old or with a minimum of 250,000 km, by a new car, which met certain emissions criteria. This scheme could also be used for second hand purchases if the car being sold is at least 12 years old and the one being bought is less than 5 years old (Jiménez et al., 2016).

The literature argues that fiscal measures provide a strong incentive to encourage the quick renewal of the car fleet and to influence consumer's behaviour toward more fuel-efficient passenger cars. In this paper it is analyzed the effectiveness of Portuguese fiscal policies in encouraging the purchase of lower carbon cars.

The article is structured as follows. Section 2 provides a literature review on policy instruments regarding the incentives for the adoption of low-$CO_2$ emission vehicles, for Portugal and for other countries. Section 3 presents the main data, the descriptive statistics, the empirical model and discusses the results and some policy implications. Section 4 concludes.

## 2. Vehicle and fuel taxation

### 2.1. The Portuguese experience

In Portugal, in 2013, the transport sector was responsible for 33.3% of energy consumption with the road transport accounting for 95% of this percentage. Furthermore, the transport sector was also responsible for 34.7% of $CO_2$ emissions, only surpassed by the energy sector that accounted for 35.2%. However, while for the power generation sector those emissions have increased nearly 5.1% relative to 1990, for the transport sector they have increased approximately 60.9% (IEA, 2016b).

$CO_2$ emissions are directly related to fuel consumption of gasoline and diesel vehicles. In Portugal, more than two out of three new bought cars are diesel cars. In 2013, oil represented 94.3% while the electricity and natural gas together accounted for 0.8% of energy consumed by transport (IEA, 2016b).

To improve the transport sector, the Government has introduced several energy efficiency measures, which form part of the updated National Energy Efficiency Action Plan (NEEAP, 2013–2016), approved by the Ministries Council Resolution n° 20/2013, namely the Eco-car Programme, the Urban Mobility Programme and the Transport's Energy Efficiency System Programme (IEA, 2016b). Regarding the former, a number of green taxes were introduced to promote the introduction of low-$CO_2$ emission vehicles - Electric Vehicles (EV) and Hybrid Vehicles (HV) - in the market. EV are exempt from the Registration Tax, also known as Tax over Vehicles (*Imposto sobre Veículos* or ISV), and from the environmental component of the annual Tax over Vehicles' Circulation (*Imposto Único de Circulação* or IUC) whereas hybrid vehicles only pay 25% of the registration tax (ACEA, 2016). The Eco-car programme also includes the Mobi.E, the electric mobility programme, which is associated with the construction and upgrading of the already existing charging infrastructures for electric vehicles. It intends to adapt it to public and private parking sites and to develop solutions for charging vehicles at home. In turn, the urban mobility programme aims at encouraging the use of collective instead of individual transport, in particular in urban areas. One way of implementing it is by promoting the introduction of more efficient vehicles in the public road transport with improved and broader networks. The Energy efficiency system for the transport sector programme consists in providing additional passenger railway networks and improving energy management in public transport fleets. Another way is by creating the adequate conditions for the everyday use of bicycles.

Currently, there are three main policy instruments affecting the price of the new passenger cars in Portugal. The vehicle registration tax, which is an up-front tax primarily based on $CO_2$ emissions and strongly graduated with increasing $CO_2$, with lower thresholds for diesel cars. The circulation tax, which is an annual tax tied to the engine power, cylinder capacity and $CO_2$ emissions. Finally, the excise taxes on fuels; and incentives through subsidies for electric vehicles.

Between 2000 and 2010, in an attempt to increase vehicle replacement through new purchases, the Portuguese government issued a car slaughter programme. This programme was replaced in 2014 by the incentive of end-of-life vehicles slaughter programme (*Incentivo ao abate de veículos em fim de vida* - VFV). The main

difference between these two programmes is that the last one only covers the so-called environmentally friendly cars. The idea is to remove vehicles with more than 10 years old from the road and reward consumers who purchase less polluting cars.

The VFV incentive through Law 82-D/2014, also called "The Green Taxation Reform", guaranteed a subsidy of 4500 euros for each new electric vehicle bought and offered a reduction in the registration tax (ISV) of 3250 euros for each new plug-in hybrid vehicle purchased. In 2016, Law 82-D/2014 was amended by Law 7-A/2016, resulting in a decrease of these incentives to 2250 euros for each new electric vehicle bought and to 1125 euros reduction in the ISV for each new plug-in hybrid vehicle purchased throughout the year 2016 and an additional 50% decrease for the 2017. More recently, DL 42-A/2016 created an incentive for the acquisition of low-emission vehicles (EV) of 2250 euros financed by the Environmental Fund, which is the successor of the Portuguese Carbon Fund. This amount allocates 1000 incentives of 2250 euros in the purchase of an electric vehicle, without the need to deliver a vehicle with more than 10 years throughout the year 2017. Table 1 describes the evolution of the Portuguese legislation regarding the energy efficiency in the Transport Sector.

In 2010, average emissions from new cars were 130 $gCO_2$/km. In 2011, Portugal was at the top of the ranking for the lowest $CO_2$ car emissions of any Member State. Nevertheless, in 2013, it dropped to the third place. In comparison to other EU member states, Portugal has relatively high purchase taxes (>30%), with a $CO_2$ emissions component that has substantially increased over the years [>€10/$gCO_2$/km] (Jiménez et al., 2016). In Portugal, relatively few cars are bought new and they are on average smaller than the EU average. Fuel taxes are low compared to most Member States but still high relative to incomes. Vehicle taxes are strongly differentiated according to $CO_2$ emissions.

The main determinant of the air pollution level by cars is the choice of the vehicle type. Portugal has reduced its conventional air pollution emissions largely due to the introduction of more performing catalytic converters and cleaner fuels. Air pollution and congestion remain a serious problem in many cities around the world, particularly due to the steady increase in car use and sales. The main cities tried to impose policies to restrict access to city centre or taxes associated to the age of the vehicles. However, the main policies to have impact in the volume of emissions may still be the national ones. Analysing city characteristics impacts with respect to sales and emissions of new cars is one of the aims of this paper with respect to Portugal.

### 2.2. Experience in other countries

There is an emerging empirical literature regarding the advantages of vehicle taxation and fuel taxation on the adoption of more environmental friendly vehicles. Although there is no consensus, some studies have emphasised the greater potential of fiscal incentives in directing towards low-carbon vehicle purchasing and ownership.

Most literature establishes that the effectiveness of car taxes depend on the type of policy adopted. Some researchers have shown that consumers respond more to rebates and sales tax exemptions that occur nearer to the moment of the purchase than to income tax incentives, which are received at some later point in time. Gass et al. (2014), for instance analyse different policy instruments, including a $CO_2$ tax, in supporting the introduction of electric vehicles in Austria. They find that an up-front price support seems to be more favourable than taxation systems in giving incentives to consumers' preferences. Accordingly, Gerlagh et al. (2016) in a study of the impacts of car taxes in 15 EU countries for 2001 and 2010 found that fiscal vehicle policies, particularly the $CO_2$-sensitivity of vehicle acquisition taxes are more effective in directing consumers to low-$CO_2$ emissions cars than annual taxes. Gallagher and Muehlegger et al. (2011), in turn, provide an example for cleaner vehicle technologies and conclude that Hybrid Electric Vehicle sales increase more because of sale tax exemptions than of income tax credits/exceptions.

Another important aspect identified by the literature is the policy-induced substitution between gasoline and diesel cars. Diesel engines are usually more efficient than gasoline engines. Besides, these cars have usually lower running costs due to their better fuel economy and the lower price of diesel in most EU countries. Fergusson (2014), for instance argues that taxing vehicles according to $CO_2$ emissions may bias the market in favour of diesel cars, since diesel cars may benefit more from the fiscal incentives as they have typically around 15% lower tailpipe $CO_2$ emissions than equivalent gasoline cars. In a comparison between diesel and gasoline cars taxation in Belgium, Mayeres and Proost (2013) found that taxes on diesel cars were much lower than on gasoline ones, which explained the differences in market shares towards diesel cars. When Ireland differentiated diesel and gasoline purchases and annual circulation taxes according to the $CO_2$ emissions released, the sales of diesel cars increased at the expense of large gasoline cars (Hennessy and Tol, 2011). Although this shift towards diesel cars has decreased $CO_2$ emissions, it caused an increase in particulates emissions and Nitrogen Oxides ($NO_x$). A similar effect was found in Norway (Thiel et al., 2010). In another study, Zachariadis (2013) examines the distribution of 17 vehicle attributes, including $CO_2$ emissions, among the German new cars market for different vehicle segments and fuels (gasoline and diesel) for the years 1998 and 2008. He concludes that $CO_2$ emissions from new cars have not decreased at the expected levels, because the substitution of gasoline for diesel cars was also linked to the improved performance and comfort of larger and powerful diesel cars, which eliminated the emissions benefit from the fuel substitution.

Another important contribution was given by Wadud (2014), who analyses the impact of the relative magnitude of both several recent policy initiatives and of the effects of fuel prices on the new car fuel economy in UK. The author concludes that not only the restructuring of Vehicle Excise Duties (VED) improved new vehicle fuel economy but also the EU $CO_2$ emission standard (EU Directive 443/2009) showed to be the largest driver for fuel economy improvements. In contrast, the effects of fuel prices were relatively small.

Some other studies point out the significant differences of the annual taxes levied on specific car types across the 27 EU Member States. At this respect, Kunert and Kuhfeld et al. (2007), argues that in response to the Regulation (EC) N° 1400/2002, that liberalises the systems for sale and distribution of vehicles, efforts should be addressed to achieve an alignment of the various tax systems in Europe for market and competitive reasons.

In the literature, several references may also be found to special programs introduced by countries with the objective of replacing polluting cars by low-$CO_2$ emissions cars. D'Haultfoeuille et al. (2016), for instance, present a study on the evolution of $CO_2$ emissions of new sold vehicles in France between 2003 and 2008. They examine the impact of both the energy label policy (from 2005) and the feebate policy based on $CO_2$ emissions of new vehicles (from 2008). They found that consumers shifted their preferences towards low-emitting cars at the time of the introduction of both policies. More recently, DeShazo et al. (2017) study the impact of alternative rebate programs for plug-in electric vehicles in California on the following four performance dimensions: sales, cost-effectiveness, total program cost and the distribution of rebate funding across consumer income classes. They identified two alternative policies superior to the *status quo* policy. One of them

**Table 1**
Main Portuguese legislation on the Energy Efficiency in the Transport Sector.

| Portuguese Legislation | EU Legislation | Objective | Amendments |
|---|---|---|---|
| Decree-Law n° 40/93, February 18th | | Regulates the vehicle tax, with all changes annually considered in the national budget legislation. Changes are in force from 1st July | Ministries Council Resolution n° 161/2005, October 12th, introduced an environmental component part. |
| Law n° 87-B/98, December 31st | | Establishes an 80% reduction in the tax rate of excise duty on environmentally friendly transport fuels, in the framework of technology development pilot projects, as long as they are duly recognised by the Ministries of Finance, Economics and Environment. | Law n° 55-B/2004 granted a full exemption (100%) in the tax rate of excise duty for biodiesel, bioethanol or ETBE (Ethyl Tertiary Butyl Ether), when incorporated in diesel and gasoline, respectively. |
| Decree-Law n° 554/99, December 16th | Council Directive n° 96/96/EC, December 20th | Regulates technical periodic inspections to the attribution of car identification plats. Confirms all vehicle (passenger, heavy and trailers) characteristics and their compliance with legal arrangements. Regulates the verification tests, the control of exhaust gas emission and the control of maximum vehicles speed | Decree-Law n° 109/2004, March 4th (Commission Directive n° 2003/27/EC, adapting to Council Directive n° 96/96/EC) reflects the EU's newer and stricter emissions limits for certain categories of motor vehicles |
| Decree-Law n° 3014/2001, November 26th | Directive 1999/94/EC of the European Parliament and of the Council, December 13th | Relates to the communication obligation of fuel economy and $CO_2$ emissions information to consumers of new passenger cars to allow an informed choice on consumption of fuel and carbon dioxide emissions. | |
| Ministries Council Resolution n° 161/2005, October 12th | | From the 1st of July 2006 on, the tax calculation formula on the purchase of passenger vehicles includes also an environmental component part, besides the cylinder capacity (CC) component. The environmental part will increase annually progressively, reducing the cylinder capacity component, favouring the less polluting vehicles. This environmental part, represented by $CO_2$ emissions, will be differentiated according to the type of fuel used. In 2006, $CO_2$ emissions represented 10% on the purchase tax vehicle, in 2007, 30% and in 2008 60%. | |
| Decree-Law n° 66/2006, March 22nd | EU Directive n° 2003/30/EC on biofuels | Establishes fiscal incentives for biofuels promotion, granting partial or total ISP excise tax (tax rate on oil products), exemption to biofuels when incorporated with gasoline or diesel used in the transport sector. | Decree-Law n° 117/2010, October 25th set that the exemption will be only applied to dedicated small producers (PPD) |
| Law n° 22-A/2007, June 29th | | Establishes fiscal differentiation to electric vehicles through total exemption of the environmental component of the Tax over Vehicles' Circulation – *Imposto Único de Circulação* (IUC) and the exemption of the Tax over Vehicles – *Imposto sobre Veículos* (ISV) | Law n° 82-D/2014, December 31st<br>Law n° 7-A/2016, March 30th |
| Ministries Council Resolution n° 20/2009 and Ministries Council Resolution n° 81/2009 | | Establishes the Mobi.E programme (Programme for Electric Mobility) with the objective of introducing and promoting the use of electric vehicles in Portugal, through the development of an innovative system that included electric grid management. | Dispatch n° 9220/2013, July 15th reviews the Mobi.E programme<br>Decree-Law n° 90/2014 extended the Programme for Electric Mobility pilot phase<br>Ordinance n° 8809/2015 defined the Action Plan for the Electric Mobility |
| Decree-Law n° 117/2010, October 25th and Ordinance n° 320-E/2011, December 30th | | Establishes the values and procedures for the exemption application of ISP. PPDs benefit from total to partial exemption of ISP up to the global limit fixed in the CIEC (*Código dos Impostos Especiais de Consumo*) that is set in 40.000 t/year. | |
| Ministries Council Resolution n° 20/2013 | | Approves the National Energy Efficiency Action Plan (NEEAP, 2013–2016) that sets several measures on the energy efficiency field, namely for the transport sector. One of the measures (Tp1m3) promotes electrical vehicles acquisition | |
| Law n° 82-D/2014, December 31st (known as "Green Taxation" legislation) | | Implements new incentives for electric and plug-in vehicles, as purchase subsidies and tax reductions | |
| Law n° 7-A/2016, March 30th | | Updates the electric and plug-in vehicles incentives | Law n° 82-D/2014, December 31st |
| Decree-Law n° 42-A/2016 | | Establishes incentives in the form of subsidies in the purchase of an electric vehicle, without the need to deliver an old vehicle (with more than 10 years old) | |

Source: Own elaboration

offers progressive rebate levels according to consumers' income with an income cap; the other applies the rebate program only to consumers with an income below $160,000, increasing the rebate levels. Previously, Diamond (2009) had studied the impact of the rebate program on the sales of a number of hybrid car models in the US (Toyota Prius, Honda Civic and Ford Escape) and found an increase of approximately 18% on sales, depending on the model. For Italy, Viesi et al. (2017) studied the implementation of the European DAFI Directive (deployment of alternative fuels infrastructure) through the Legislative Decree n.257, which for Italy meant

including hydrogen in the list of alternative fuels. For the 2050 time horizon, the authors applied a recommended methodology for sizing fleets and hydrogen demand at the refuelling stations, for hydrogen production for the transport sector, to combine renewables with hydrogen storage to infer the consumer needs and to and for sizing hydrogen refuelling stations, among others aspects. For China, Du et al. (2017) show that constraining vehicle registration is the most effective measure for reducing fuel consumption, provided that the tremendous increase in vehicle population turned road transport a major source of air pollution emissions. However, they recommend an additional strength of vehicle emission standards to fighting air pollution emissions.

Regarding the analysis of the impact of policy measures in the EU as a whole, Ajanovic and Hass (2017) discuss and compare GHG emission reductions due to different policy measures implemented in passenger car transport in the EU-15. They applied a new developed methodology based on scenarios to conclude that GHG emissions could be reduced at least by 33% in a selected policy scenario up to 2030. Also for the EU, Thiel et al. (2016) analyzed the impact of the current and of the alternative stricter $CO_2$ car legislation on transport related $CO_2$ emissions considering the uptake of electric vehicles, the oil consumption reduction and the total energy system cost beyond 2020. Their 2030 simulation results show that a stricter target of 70 $gCO_2$/Km for cars could reduce total transport $CO_2$ emissions by 5% and oil dependence by more than 2%, when compared to the current legislation.

Although there are many countries that have introduced special programs aimed at increasing vehicle replacement through new low-carbon vehicles purchases, little attention has been paid to their impact on sales and prices. At the top of our knowledge, there are very few studies of their effect in European countries and no studies for Portugal. Jiménez et al. (2016) carried out a study about the impact of the Plan 2000E in Spain that promotes pollution reducing vehicles from three perspectives: on the price set by automobile manufacturers (the effect of subsidy on price), on the sales of automobiles and on the viability of the program regarding the environmental benefits. The results indicate a significant increase in prices of the subsidized vehicles, showing that the manufacturers keep the highest part of the price for themselves and therefore, the effect on sales is not as expected.

More recently, it has been observed in the literature the emergence of some studies considering decision making and consumer's behaviour towards road vehicles. Marcilio et al. (2018), for instance, analyzed the behaviour of environmental and performance variables in the context of road freight transportation. The authors used a survey (a satisfaction questionnaire) to evaluate the customers, workers, and managers perception concerning the environment. They conclude that managers can possibly develop different sustainable strategies considering the type of commercial vehicle available in the company, the vehicle age and the eco-driving behaviour among drivers. Using scenario analysis of energy mix for the road transportation sector in Indonesia, Deedarlianto et al. (2017) argue that gasoline and diesel seem to be unfeasible options in the future, mostly due to their limited availability, high subsidy dependency and environmental issues.

## 3. Empirical results and policy implications

### 3.1. Descriptive analysis of new car sales in Portugal

In this section, we present a description on the evolution of sales in the Portuguese new cars market for the period between 2002 and 2016, with a special focus on the data related to the years of 2006 and 2013, when significant changes in the legislation had occurred. All data comes from ACAP (Associação Automóvel de Portugal – Portuguese Automobile Association; www.acap.pt). The database contains information with respect to monthly sales of new cars in Portugal including models, engine size, power, car characteristics, among others, except the region of sales.

In Table 2, it can be observed that in 2006 the segment with higher sales was the Berlina 5D (B5), representing almost half the market with 47.61% of the total units sold, followed by the Station Wagon (SW) segment with a share of 21.48% of the market. For the Gasoline type of fuel, the B5 segment is completely dominant, taking 73% of the whole sales. The diesel powered engines have a more balanced distribution between the two top segments, with the B5 accounting for 35.44% and the SW accounting for 31.19% of total sales. Another relevant fact that can be seen in Table 2 is the relative low number of availability and sales of both models in the electric and hybrid vehicles category.

Regarding the data for 2013, Table 3 shows that for the total car sales, there has not been a great difference in the distribution relatively to 2006. The two most sold segments are the same, with a slightly growth in the B5 to 49.97%, again followed by the SW, now with 18.94% of sales. A major difference between these two years is the growth in the number of electric and hybrid vehicles sold, accompanying the increase in diversification offered in models and segments.

Analyzing the B5 segment for $CO_2$ emissions and engine capacity (in Cubic Centimeters), in Fig. 1 we may easily detect that for the period in analysis the sales of new cars have occurred mainly in lower $CO_2$ emissions classes with the distribution shifting to the left. While in 2006, still more than 50% of sales in the gasoline vehicles, occurred in classes between 130 and 149 g/km, and in the diesel fuel, the modal class was clearly the 120–129 g/km, in 2013 for both fuel types, the majority of sales take place in vehicles with emissions bellow 120 g/km.

In Fig. 2, it is possible to note that this shifting towards fewer emissions had occurred not just in the sales, but also in the number of vehicles available in the market. Therefore, producers in this industry are adjusting their offers to the consumers' preferences for economical vehicles (fiscal incidence regarding $CO_2$ emissions can considerably increase the car price) and to a stricter legal framework in terms of $CO_2$ emissions. In 2006, the distribution of available vehicles is far less concentrated in the lower emission classes, although the actual sales do not follow the same path, having a higher skewness to the left. For the class 150–159 g/km and upward the relation of vehicles available and sold, shows that even though there were offers in those segments, consumers do not tend to buy those kind of vehicles.

In Fig. 3, it is possible to verify a very similar relation but concerning the engine capacity. The Portuguese market faced a movement toward higher share of sold cars with smaller engines. Cars are more efficient but with smaller engines without loss of performance.

The evolution for this period (2006–2013) on the main characteristics analyzed are described in Table 4. For all types of fuels, the Horse Power of the engines has increased while the CC capacity has reduced (gasoline, diesel, and hybrid). This evolution was possible even with a significant reduction of $CO_2$ emissions (−21% and −17.6%). It is also possible to perceive that the ratio between the Diesel cars and gasoline alternatives improved, increasing the advantage they already have in terms of fuel efficiency and $CO_2$ emissions.

Considering the number on total cars sold in Portugal between 2002 and 2016, it is clear the importance of diesel cars relatively to the gasoline cars (see Fig. 4). Until 2003, the gasoline cars were the most sold models, like in other EU countries. From this year on, the diesel vehicles sales have replaced the gasoline ones on the top of sales. In Fig. 4 it can also be observed the effect of the economic and financial crises on new cars sales after 2011, with a clear decrease in

**Table 2**
Descriptive statistics – new car market – 2006.

| | n° Models | % Models | Engine Pwr (cc) | $CO_2$ Emissions | | Horse Pwr (hp) | Sales | |
|---|---|---|---|---|---|---|---|---|
| | | | Mean | mean | Std. Dev. | mean | n° cars | Share (%) |
| **2006 - All** | | | | | | | | |
| Berlina 3D | 467 | 13.10% | 1467.20 | 140.29 | 22.54 | 72.04 | 12,288 | 6.31% |
| Berlina 5D (B5) | 869 | 24.37% | 1517.61 | 144.60 | 23.02 | 73.36 | 92,705 | 47.61% |
| Cabrio | 150 | 4.21% | 2011.65 | 182.31 | 65.57 | 117.59 | 2466 | 1.27% |
| S. Weagon (SW) | 529 | 14.83% | 1921.36 | 165.28 | 32.80 | 100.68 | 41,821 | 21.48% |
| Commercial | 34 | 0.95% | 1437.38 | 151.21 | 15.65 | 57.91 | 1394 | 0.72% |
| Coupe | 173 | 4.85% | 2573.92 | 210.55 | 91.32 | 160.75 | 3681 | 1.89% |
| CUV | 30 | 0.84% | 2204.67 | 189.47 | 47.22 | 113.23 | 546 | 0.28% |
| MonoVolume | 469 | 13.15% | 1727.28 | 164.41 | 28.09 | 83.96 | 17,454 | 8.96% |
| Roadster | 59 | 1.65% | 2401.12 | 205.59 | 62.03 | 144.90 | 986 | 0.51% |
| Sedan | 581 | 16.29% | 2241.62 | 180.61 | 46.34 | 122.60 | 16,405 | 8.43% |
| 4 × 4 (off-road) | 205 | 5.75% | 2553.90 | 232.66 | 54.95 | 129.84 | 4956 | 2.55% |
| Total | 3566 | 100.00% | 1867.68 | 166.87 | 47.76 | 97.38 | 194,702 | 100.00% |
| **2006 - Gasoline** | | | | | | | | |
| Berlina 3D | 241 | 16.35% | 1378.95 | 151.32 | 23.19 | 71.68 | 6358 | 9.46% |
| Berlina 5D (B5) | 421 | 28.56% | 1384.53 | 153.06 | 22.05 | 69.88 | 49,437 | 73.53% |
| Cabrio | 106 | 7.19% | 2078.37 | 196.73 | 70.29 | 125.92 | 1130 | 1.68% |
| S. Weagon (SW) | 143 | 9.70% | 1832.77 | 182.55 | 42.64 | 102.82 | 3484 | 5.18% |
| Commercial | 9 | 0.61% | 1329.11 | 171.78 | 10.81 | 56.67 | 223 | 0.33% |
| Coupe | 113 | 7.67% | 2808.11 | 238.68 | 97.98 | 186.05 | 1632 | 2.43% |
| CUV | 8 | 0.54% | 2375.63 | 205.38 | 57.11 | 124.13 | 140 | 0.21% |
| MonoVolume | 110 | 7.46% | 1432.15 | 166 | 18.61 | 71.68 | 1929 | 2.87% |
| Roadster | 57 | 3.87% | 2421.6 | 207.49 | 62.04 | 146.51 | 832 | 1.24% |
| Sedan | 212 | 14.38% | 2384.35 | 208.15 | 55.34 | 140.34 | 1752 | 2.61% |
| 4 × 4 (off-road) | 54 | 3.66% | 2895.2 | 258.31 | 75.75 | 168.81 | 316 | 0.47% |
| Total | 1474 | 100.00% | 1833.98 | 180.59 | 57.89 | 103.38 | 67,233 | 100.00% |
| **2006 – Diesel** | | | | | | | | |
| Berlina 3D | 226 | 10.90% | 1561.32 | 128.52 | 14.42 | 72.42 | 1910 | 1.56% |
| Berlina 5D (B5) | 448 | 21.60% | 1642.67 | 136.66 | 21 | 76.63 | 43,268 | 35.44% |
| Cabrio | 43 | 2.07% | 1870.74 | 148.56 | 32.11 | 98.6 | 1336 | 1.09% |
| S. Weagon (SW) | 382 | 18.42% | 1956.99 | 158.69 | 25.49 | 100.06 | 38,326 | 31.39% |
| Commercial | 25 | 1.21% | 1476.36 | 143.8 | 9.16 | 58.36 | 1171 | 0.96% |
| Coupe | 58 | 2.80% | 2171.98 | 159.47 | 40.27 | 115.21 | 2049 | 1.68% |
| CUV | 22 | 1.06% | 2142.5 | 183.68 | 41.58 | 109.27 | 406 | 0.33% |
| MonoVolume | 359 | 17.31% | 1817.72 | 163.92 | 30.4 | 87.72 | 15,525 | 12.72% |
| Roadster | 2 | 0.10% | 1817.5 | 151.5 | 27.5 | 99 | 154 | 0.13% |
| Sedan | 360 | 17.36% | 2151.83 | 165.06 | 29.93 | 111.48 | 13,956 | 11.43% |
| 4 × 4 (off-road) | 149 | 7.18% | 2428.88 | 223.83 | 41.73 | 115.5 | 3984 | 3.26% |
| Total | 2074 | 100.00% | 1889.86 | 157.23 | 35.98 | 92.93 | 122,085 | 100.00% |
| **2006 - Electric and Hybrid** | | | | | | | | |
| Cabrio | 1 | 8.33% | 999 | 105 | 0 | 52 | 2 | 1.82% |
| Coupe | 2 | 16.67% | 999 | 103 | 0 | 52 | 4 | 3.64% |
| Sedan | 8 | 66.67% | 2530.88 | 147.25 | 48.15 | 153.38 | 69 | 62.73% |
| 4 × 4 (off-road) | 1 | 8.33% | 3311 | 192 | 0 | 200 | 35 | 31.82% |
| Total | 12 | 100.00% | 2212.92 | 140 | 46 | 131.917 | 110 | 100.00% |

Source: Own calculations based on ACAP sales database.

the number of new cars sold, between 2012 and 2014. After the bottom reached in that year, the market is recovering in the last couple of years. Overall, it is noticed that the greatest number of cars sold in Portugal from 2000 until 2016 are those based on diesel. However, in the last years more electrical cars were sold in the Portuguese market, facing a steady growth rate since 2013. This occurs essentially for three reasons. Firstly, a considerable higher diversity of models (12 in 2006 and 81 in 2013) are now available to the population and the number of segments were previously almost inexistent (4 segments in 2006 and 8 segments in 2013). Secondly, the price of these vehicles has fallen, both due to the fiscal incentives and to the evolution of the technology, mainly regarding the batteries sector. Last, but not least, due to the infrastructures, particularly, the Electric Vehicle Charging Stations network have grown in the last couple of years (e.g. in 2016, GALP announced that it was possible to drive from the north to the south of Portugal – 800 km – always encountering a Fast Charge Station).

Regarding the $CO_2$ emissions by new cars, in 2013 its average was of 112,2 $gCO_2/km$ (- 31.1% compared to 2000) due to new and efficient technology in car making, which is also a reflection of specific legislation that establishes $CO_2$ minimum requirements. We clearly notice a decrease in the average $CO_2$ emissions of sold cars throughout time for the overall categories. This evolution is due to a clear concern in manufacturing less pollutant cars (Fig. 5) to comply with legislation and to avoid being punished by taxation. Although there are many models available over a wide range of engine sizes and by emission classes, it is observed a clear concentration of sold cars in some classes for all segments throughout the years. Thus, it is perceived a downward evolution with respect to large models with high emission levels, which exhibit a smaller percentage in total sales over time. This also means that very powerful and high-emitting cars are less popular among consumers (as in Zachariadis (2013) for Germany). This change in the purchasing behaviour may also be induced by the legislation and by

**Table 3**
Descriptive statistics new car market – 2013.

| | n° Models | % Models | Engine Pwr (cc) | $CO_2$ Emissions | Horse Pwr (hp) | | Sales | |
|---|---|---|---|---|---|---|---|---|
| | | | Mean | Mean | Std. Dev. | Mean | n° cars | Share (%) |
| **2013 – All** | | | | | | | | |
| Berlina 3D | 463 | 13.07% | 1434.75 | 118.7 | 22.67 | 82.603 | 5672 | 5.42% |
| Berlina 5D (B5) | 993 | 28.03% | 1455.9 | 116.6 | 20.4 | 78.751 | 52,332 | 49.97% |
| Cabrio | 132 | 3.73% | 1935.6 | 147.1 | 49.24 | 127.56 | 1128 | 1.08% |
| S. Weagon (SW) | 535 | 15.10% | 1858.8 | 131.7 | 24.2 | 109.46 | 19,840 | 18.94% |
| Commercial | 41 | 1.16% | 1548 | 130.3 | 23.54 | 72.585 | 426 | 0.41% |
| Coupe | 150 | 4.23% | 2783.4 | 180.4 | 75.02 | 205.35 | 2690 | 2.57% |
| CUV | 194 | 5.48% | 1647.2 | 139 | 20.73 | 93.139 | 8102 | 7.74% |
| MonoVolume | 280 | 7.90% | 1634.8 | 134.4 | 22.72 | 89.1 | 4078 | 3.89% |
| Roadster | 32 | 0.90% | 2682.4 | 182.6 | 47.57 | 178.33 | 108 | 0.10% |
| Sedan | 475 | 13.41% | 2194.3 | 139.2 | 34.99 | 139.47 | 5582 | 5.33% |
| 4 × 4 (off-road) | 248 | 7.00% | 2284.9 | 167.2 | 43.84 | 137.06 | 4771 | 4.56% |
| Total | 3543 | 100.00% | 1783.4 | 133 | 36.17 | 105.77 | 104,729 | 100.00% |
| **2013 – Gasoline** | | | | | | | | |
| Berlina 3D | 264 | 21.78% | 1314.1 | 124.7 | 23.84 | 81.51 | 2658 | 9.51% |
| Berlina 5D (B5) | 439 | 36.22% | 1266.4 | 123.1 | 18.19 | 73.70 | 20,607 | 73.69% |
| Cabrio | 68 | 5.61% | 2072.2 | 163.9 | 57.41 | 150.28 | 444 | 1.59% |
| S. Weagon (SW) | 102 | 8.42% | 1607.6 | 142.6 | 37.14 | 105.65 | 1460 | 5.22% |
| Commercial | 0 | 0.00% | – | – | – | – | 0 | 0.00% |
| Coupe | 90 | 7.43% | 3202.1 | 213.2 | 77.06 | 245.97 | 1058 | 3.78% |
| CUV | 57 | 4.70% | 1529.9 | 147.1 | 15.83 | 93.75 | 1059 | 3.79% |
| MonoVolume | 48 | 3.96% | 1292.8 | 136.4 | 16 | 78.94 | 315 | 1.13% |
| Roadster | 26 | 2.15% | 2887.5 | 195 | 45.98 | 193.27 | 43 | 0.15% |
| Sedan | 83 | 6.85% | 2396.2 | 168.9 | 52.07 | 168.16 | 204 | 0.73% |
| 4 × 4 (off-road) | 35 | 2.89% | 2647.5 | 200.5 | 52.9 | 178.69 | 116 | 0.41% |
| Total | 1212 | 100.00% | 1659.9 | 142.6 | 46.14 | 108.39 | 27,964 | 100.00% |
| **2013 – Diesel** | | | | | | | | |
| Berlina 3D | 195 | 8.78% | 1620.7 | 111.7 | 14.86 | 83.944 | 2999 | 3.99% |
| Berlina 5D (B5) | 502 | 22.59% | 1635.6 | 113.2 | 15.1 | 84.062 | 30,543 | 40.66% |
| Cabrio | 62 | 2.79% | 1848.2 | 133.3 | 18.68 | 105.31 | 679 | 0.90% |
| S.Weagon (SW) | 430 | 19.35% | 1917.2 | 129.6 | 18.91 | 110.13 | 18,307 | 24.37% |
| Commercial | 41 | 1.85% | 1547.9 | 130.34 | 23.54 | 72.6 | 426 | 0.57% |
| Coupe | 53 | 2.39% | 2294.6 | 138.87 | 17.89 | 150.72 | 1580 | 2.10% |
| CUV | 136 | 6.12% | 1696.7 | 135.36 | 21.49 | 92.97 | 7017 | 9.34% |
| MonoVolume | 228 | 10.26% | 1705.8 | 134.39 | 23.69 | 91.1 | 3742 | 4.98% |
| Roadster | 6 | 0.27% | 1920.6 | 136.29 | 9.91 | 122.86 | 65 | 0.09% |
| Sedan | 361 | 16.25% | 2135.3 | 135.06 | 21.50 | 129.44 | 5134 | 6.83% |
| 4 × 4 (off-road) | 208 | 9.36% | 2214.8 | 162.9 | 38.86 | 128.79 | 4633 | 6.17% |
| Total | 2222 | 100.00% | 1855.95 | 129.53 | 25.98 | 104 | 75,125 | 100.00% |
| **2013 - Electric and Hybrid HyHybridHybrid** | | | | | | | | |
| Berlina 3D | 2 | 2.47% | 647 | 6.5 | 6.5 | 125 | 10 | 0.81% |
| Berlina 5D (B5) | 28 | 34.57% | 1430.8 | 66.25 | 43.25 | 81.5 | 442 | 35.99% |
| Cabrio | 2 | 2.47% | 0 | 45 | 10 | 0 | 5 | 0.41% |
| S. Weagon (SW) | 7 | 8.64% | 1932.6 | 101.3 | 9.735 | 123.43 | 377 | 30.70% |
| Coupe | 8 | 9.88% | 1310.1 | 85.63 | 69.09 | 110.38 | 52 | 4.23% |
| MonoVolume | 3 | 3.70% | 1798 | 97.67 | 2.357 | 100 | 17 | 1.38% |
| Sedan | 30 | 37.04% | 2407.1 | 107.6 | 51.92 | 184.73 | 324 | 26.38% |
| 4 × 4 (off-road) | 1 | 1.23% | 2554.7 | 126.3 | 44.84 | 174.43 | 1 | 0.08% |
| Total | 81 | 100.00% | 2207.9 | 110.2 | 35.24 | 150.25 | 1228 | 100.00% |

Source: Own calculations based on ACAP sales database.

the taxes paid according to the $CO_2$ emissions, which are higher for high-emitting cars.

### 3.2. Empirical modelling and analysis

In this section, we will use an empirical modelling approach to capture if the effect of the introduction of legislation in this sector has effect in the actual sales and/or environmental performance of the vehicles. We follow the same methodology adopted by Wadud (2014), although we apply ordinary least squares to a different set of variables.

#### 3.2.1. Variables/data

The dependent variables we use to perform the regression analysis are the average monthly $CO_2$ emissions for all sold cars, measured as the average $CO_2$ emissions weighted by the effective number of sales in the respective month (zeros were excluded from the accounting of sales) and the average monthly sales of all cars. After the regressions of the global market we also perform the analyses for each type of fuel (gasoline, diesel and electrical cars - hybrid number of sold cars are not considered in this accounting). We have also included as regressors the average monthly $CO_2$ emissions for all sold cars and by type of fuel, when the dependent variable is the average monthly sales, and the average monthly sales, when the dependent variable is the average monthly emissions weighted by sales.

In each regression, we have included several other independent variables trying to capture different dimensions of this problematic. As for some of the main important characteristics of the vehicles we use the average engine size (in CC; the monthly average of engine size

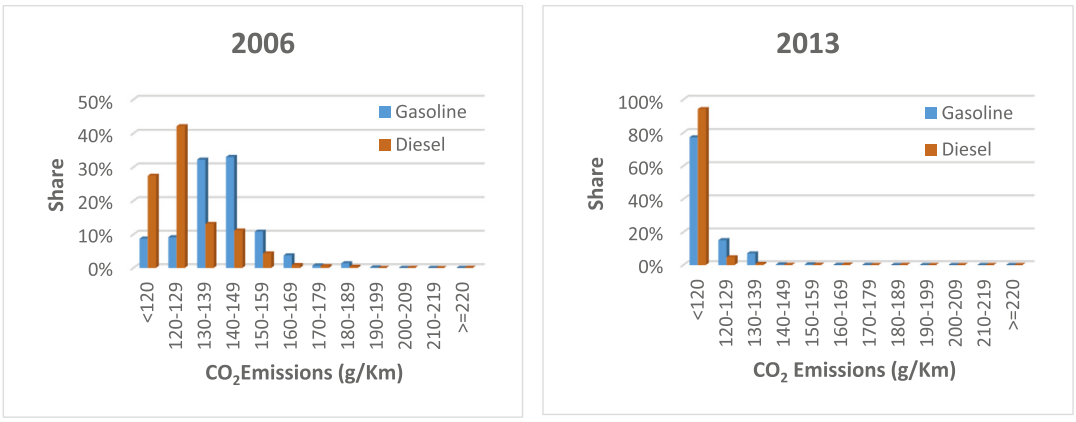


**Fig. 1.** Car sales share distribution by $CO_2$ (B5 – Berlina 5D).

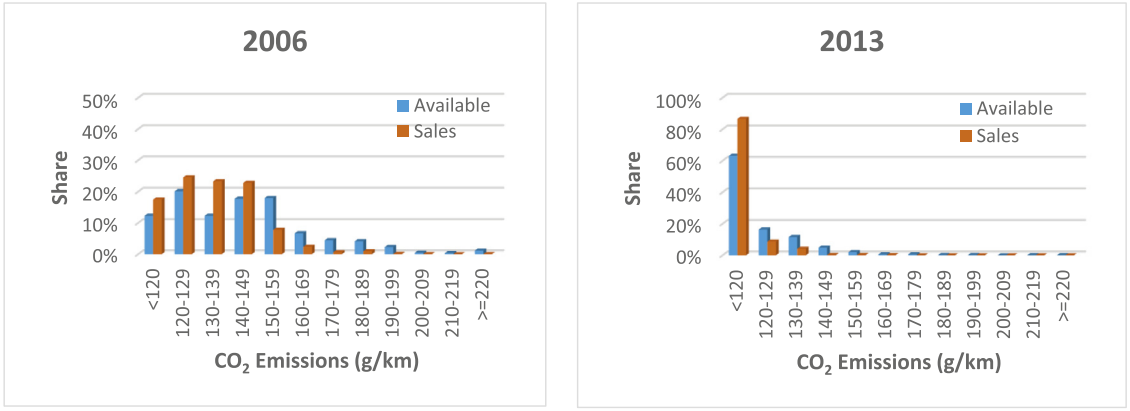


**Fig. 2.** Available models and car sales distribution by $CO_2$ (B5 – Berlina 5D).

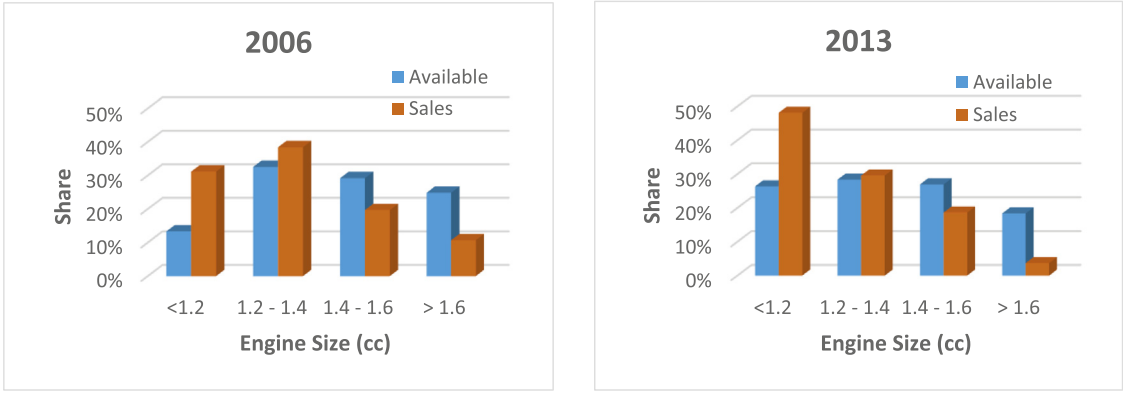


**Fig. 3.** Available models and car sales distribution by CC (B5 – Berlina 5D).

multiplied by the monthly sales) and the average monthly power (in horse power; the monthly average of power multiplied by the monthly sales). To account for the effect of population size in the acquisition of new cars we use annual data with respect to population density (reproduced equally for all months in a given year), collected from Eurostat[1] computed as inhabitants per $km^2$, and by NUTS (Portugal, the Lisbon Metropolitan area, and the North Porto region).

Since economic conditions of a country or a region are crucial for the decision to buy a new car, we also include a set of economic variables in our analyses. We include 1) annual data with respect to net disposable income of households measured in euro per inhabitant (reproduced monthly through the respective year), by NUTS, also collected from Eurostat; 2) annual data with respect to the employment rate, collected from Eurostat as well, reproduced monthly, by NUTS, considering indifferences with respect to gender of the population with 15–64 years, measured in percentage terms; 3) Long-term interest rates, per cent per year, in monthly terms

[1] http://ec.europa.eu/eurostat/web/regions/data/main-tables - Accessed on 10 May 2017.

**Table 4**
Newly cars Attributes evolution 2006–2013.

| | 2006 | 2013 | Change |
|---|---|---|---|
| **Gasoline** | | | |
| Hp | 103.38 | 108.39 | 4.85% |
| Cc | 1833.98 | 1659.9 | −9.49% |
| $CO_2$ | 180.59 | 142.6 | −21.04% |
| **Diesel** | | | |
| Hp | 92.93 | 104.0081 | 11.92% |
| Cc | 1889.86 | 1855.954 | −1.79% |
| $CO_2$ | 157.23 | 129.5286 | −17.62% |
| **Ratio Diesel/Gasoline Cars** | | | |
| Hp | 0.90 | 0.96 | 6.75% |
| Cc | 1.03 | 1.12 | 8.51% |
| $CO_2$ | 0.87 | 0.91 | 4.33% |
| **Hybrid_Electric** | | | |
| Hp | 131.917 | 150.25 | 13.90% |
| Cc | 2212.92 | 2207.9 | −0.23% |
| $CO_2$ | 140 | 110.2 | −21.29% |
| **Ratio Hybrid_Electric/Diesel Cars** | | | |
| Hp | 1.42 | 1.44 | 1.77% |
| cc | 1.17 | 1.19 | 1.60% |
| $CO_2$ | 0.89 | 0.85 | −4.45% |

Source: Own calculations based on ACAP sales database.
Note: Hp stands for horse power; CC represents engine power.

collected from OECD[2] stats, to account for the possibility of requesting a loan when purchasing the car; and 4) monthly unemployment rates collected from OECD database, *proxy* for living conditions of the population.

Moreover, we consider data on the two major cities with respect to population density, employment rate and net disposable household income in estimations for Portugal, the metropolitan area of Lisbon and the north region of Porto, in order to analyse whether sales and $CO_2$ emissions depend on the city under analysis. The reason is mainly because, following ACAP[3] – Portuguese Automobile Association – information, Lisbon was the area with more automobile density in 2010, followed by Porto. Therefore, we consider that these are the two cities with more emissions issued by new cars sales.

We have also included in our model the behaviour of fuel prices using the annual average selling prices of gasoline and diesel in Portugal. These data was collected from Pordata[4] database and used in monthly terms. Finally, we introduce a dummy variable to account for the laws introduced, with respect to taxes over polluting cars. We assume the value 1 in the periods between November 2005 and June 2007, from February 2009 until January 2010, from April 2013 until March 2014 and from December 2014 until December 2015, and the value 0 in all the other periods. For this different classification, we consider the information on legislation summary presented in Table 1.

In order to eliminate unit root possibilities, all variables used in the estimations were transformed into logs except the dummy variable to guarantee variables stationarity. Robust standard errors were accounted in estimations to avoid potential biases and the results are presented in Table 5. Other relevant variables from the original database could be included into estimations, namely the type of car, model, variant, brand, power class, engine size class, number of doors, among others.

### 3.2.2. Results and analyses

Regarding results and analysis performed previously, the following will describe the major results attained in terms of legislation effects; results considering vehicles' characteristics; we perform an analysis of the economic environment effects; a brief discussion of fuel prices is to be presented also; and we end up by discussing some population density effects, allowed by the analysis undertaken.

*3.2.2.1. Legislation.* From Table 5 we may take some interesting conclusions, namely the fact that there are common variables with explanatory and statistical significance when the dependent variable is average sales, though revealing no statistical significance when emissions is the considered dependent variable. The most notable variable is the dummy for the legislation changes, meaning that new laws introduced in Portugal have a clear significant and positive effect over average sales, but not over average $CO_2$ emissions weighted by monthly sales. The exception is the case of gasoline cars, where the introduction of new laws seems to have a negative and significant influence. This is the case because gasoline cars were some of the most penalised vehicles in terms of legislation, since these cars were those that presented higher average $CO_2$ emissions during the entire period and new laws over highly polluting cars are harder. Thus, regarding the environment, we may have here a perverse effect. Since consumers choose to buy cars with lower emissions, they will certainly pay lower taxes in order to save money. This does not necessarily mean that they choose this type of cars due to environmental awareness and consciousness. Nevertheless, it could mean that they rather do that because they weight the additional tax-cost charges. There are other relevant variables, namely the type of car, model, variant, brand, power class, engine size class, number of doors, among others, that could be interesting to analyse and might affect new car purchasing. These factors could also be important to consider and justify buying behaviour due to the increase in the number of electrical cars sold in the most recent years. The green taxation legislation results with positive and statistically significant effect of the law dummy on the average sales of electrical cars, may not state the environmental consciousness increases of customers as the only reason for this effect, as this environmental friendly decision, may be just due to the tax exemption effect regarding electrical cars.

For France, D'Haultfoeuille et al. (2016) investigate the effect of two introduced policies (energy label requirement and feebate based on $CO_2$ emissions of new vehicles) on the evolution of $CO_2$ emissions of new vehicles sold between 2003 and 2008. They conclude that there has been a shift in preferences towards low-emitting cars. For Germany, Zachariadis (2013) concludes that households prefer to have cars that are more powerful even if that implies higher emissions, evidencing lower environmental consciousness and awareness. For Portugal, our results seem to be more in line with D'Haultfoeuille et al. (2016) conclusions.

*3.2.2.2. Vehicles' characteristics.* Except for electrical cars, average sales have a positive and significant influence over average monthly emissions and vice-versa showing that there is a clear impact between the two variables. Moreover, average engine size has a significant negative effect over sales and a positive influence over emissions though it is not statistically significant over electrical vehicles. As evidenced by Fig. 3 we observe that both engine size and power of diesel cars were higher than in the other car categories. However, engine size has slightly declined throughout time, but at the same time, it can be observed an increased engine power. This allied to the fact that emissions have clearly decreased for all

[2] http://stats.oecd.org/- Accessed on 10 May 2017.
[3] http://www.acap.pt/pt/pagina/36/estat%C3%ADsticas/- Information accessed in 10 May 2017.
[4] http://www.pordata.pt/Portugal/Pre%C3%A7os+m%C3%A9dios+de+venda+ao+p%C3%BAblico+dos+combust%C3%ADveis+l%C3%ADquidos+e+gasosos+%E2%80%93+Continente-1265 – Accessed on 10 May 2017.

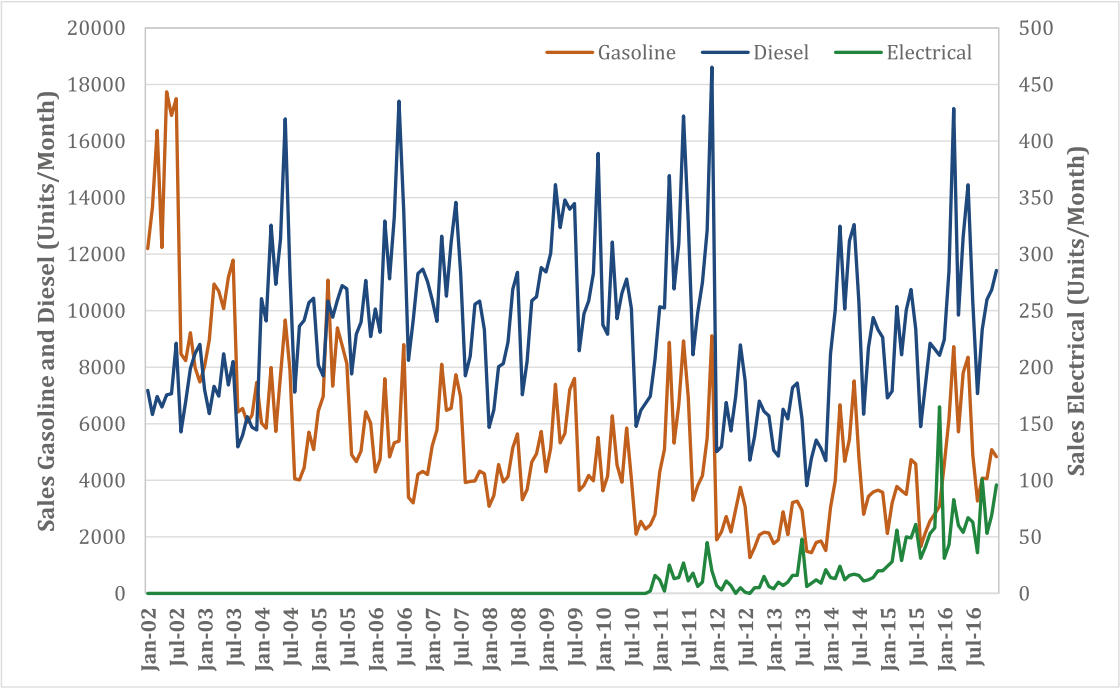


**Fig. 4.** Sales of New Cars per month by Fuel Type between January 2002 and December 2016 (left vertical axis respects to sales values of gasoline and diesel cars; the right vertical axis respects to sales values of electric cars).

**Fig. 5.** Average $CO_2$ Emissions of New Cars sold in Portugal (Jan 2002–Dec 2016).

categories (Fig. 1) we may state that technology evolution has contributed to the simultaneous increase of power in cars and accommodation of legislation with environmental concerns. According to Zachariadis (2013), in Germany, for all car types, vehicles have become more powerful and with less $CO_2$ emissions to roughly the same engine size. In Portugal, gasoline car sales also have shifted towards lower emitting models. In diesel sales, we observe a positive and significant impact of engine power, showing a slight decrease through time even though the average engine power of all cars reveals a positive trend.

**Table 5**
Least Squares estimation results considering as dependent variables average monthly sales and average monthly $CO_2$ emissions by type of fuel/car and all new car sold: January 2002–December 2016.

| | | Dependent variable | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Av. All $CO_2$ | Av. All Sales | Av. Gasol. $CO_2$ | Av. Gasol. Sales | Av. Diesel $CO_2$ | Av. Diesel Sales | Av. Electrical $CO_2$ | Av. Electrical Sales |
| Regressors | Av. $CO_2$ emissions | | 2.3675** | | 4.7621*** | | 3.5300** | | −0.0514 |
| | Av. Sales | 0.0136** | | 0.0145*** | | 0.0100** | | −0.2215 | |
| | Av. Eng. Size | 0.8422*** | −5.4611*** | 0.8735*** | −4.5244** | 0.7265*** | −8.9166*** | −0.0707 | −0.0180 |
| | Av. Power | −0.3695*** | −1.9213* | −0.1178** | −6.0747*** | 0.0088 | 0.4064*** | 0.0750 | 0.4747*** |
| | Long Term Int. Rate | −0.0019 | 0.0066 | 0.0073 | −0.3260** | 0.0098* | −0.0584 | 0.6456 | −0.2105 |
| | Unemploym. Rate | −0.0518*** | −0.2883 | −0.0692*** | −1.0101*** | 0.0162 | −0.1156 | −5.2941*** | −0.7154 |
| | Dummy law | −0.0031 | 0.1023*** | −0.0102*** | 0.1099** | −0.0023 | 0.0657* | 0.3383 | 0.4376*** |
| | Av. Gasoline fuel prices | −0.0353 | 1.9775** | −0.0220 | 0.4857 | −0.1764*** | 1.3452 | 5.3700 | 5.3617** |
| | Av. Diesel fuel prices | −0.3216*** | −0.2233 | −0.1917*** | −1.5846* | −0.0750** | −0.9196 | 2.5114 | −1.1762 |
| | Net Disp. Income PT | 0.0187 | −9.8858** | 0.1359 | −27.6765*** | 1.8107*** | −20.6056*** | 43.3978 | −57.6453*** |
| | Net Disp. Income Lisbon | 1.2357*** | 4.3256 | 0.9035*** | 10.4348** | 1.3682*** | 3.2749 | −21.2942 | 28.1763*** |
| | Net Disp. Income Porto | 0.4571* | 1.5543 | −0.1514 | 16.0708*** | −1.4372*** | 12.2642*** | −37.7162** | 10.4447 |
| | Employment rate PT | −1.3572** | 5.1567 | −0.2518 | −32.8254*** | 1.6993*** | −7.8082 | 20.3656 | 27.0948 |
| | Employment rate Lisbon | −3.8518*** | 15.5144*** | −2.7958*** | 28.9807*** | −5.2141*** | 20.7922** | 50.7025** | 21.9685* |
| | Employment rate Porto | 5.0913*** | −15.8027** | 3.2585*** | −3.2219 | 3.9315*** | −9.1030 | −92.9670*** | −33.57,595*** |
| | Pop. Density PT | −19.0938*** | 85.5933*** | −13.1185*** | 132.5694*** | −24.9661*** | 105.5765** | 125.5337 | 278.1467*** |
| | Pop. Density Lisbon | 4.2423*** | −24.5211*** | 3.8278*** | −34.8278*** | 5.8198*** | −29.8841*** | −83.3737*** | −10.3447 |
| | Pop. Density Porto | 9.2900*** | −36.0244* | 4.8536*** | −54.3865** | 11.4194*** | −43.0574* | 40.6155 | −205.9291*** |
| | Adj. $R^2$ | 0.9934 | 0.7750 | 0.9940 | 0.8506 | 0.9959 | 0.6970 | 0.4637 | 0.9228 |

Method: Least Squares; Sample: 2002M01 2016M12; Included observations: 180.
Note: Av. stands for average, Gasol. stands for gasoline, Disp. is disposable, PT is Portugal, Pop. denotes population. *, **, *** represent coefficients statistically significant at 10%, 5% and 1%, respectively. The presented values are regression coefficient estimates. Av. $CO_2$ emissions and average sales as regressions change depending on the type of fuel/car (all new sales, gasoline, diesel and electrical) respectively for each of the considered dependent variables.

*3.2.2.3. Economic environment.* The long-term interest rate, as representative of the price payed for requested loans, has a negative and significant impact over gasoline sales. Thus, an increase in the interest rates lowers the volume of sales of gasoline cars. This is a very intuitive result since in Portugal a large majority of car sales is anchored to credit and hence, as the price of money increases the access to credit drops. Higher unemployment rates mean lower average of gasoline car sales as well as lower average emissions in all new car sales, and in the gasoline emissions and electrical emissions. Therefore, higher interest rates and higher unemployment rates are responsible for lower sales, meaning that the economic overall conditions and households living conditions justify sales decrease of new cars, since they hold lower disposable income to buy new cars. This is also evident for the variable net disposable income of Portuguese population, whose results show a negative and highly significant influence over sales independently of the car type (gasoline, diesel and electrical).

Kitapci et al. (2014) studied the effect of economic policies as one of the macro environmental factors responsible for marketing in car sales in Turkey, using monthly data from 2005 to 2010. They have applied multiple regression analysis as we do and neural network methods to find that vehicle loan rates and tax deduction for the automobile sector affected automobile sales, although inflation rate, automobile and oil prices, consumers' income and advertising expenditures seem to have no effect over sales. In our results higher net disposable income for Portugal as a whole exerts a negative impact over sales of new cars independently of the class and a positive effect over emissions regarding diesel cars. However, when we consider only disposable income in terms of greater cities (those with a higher average of circulating cars per capita: Lisbon and Porto), the results indicate that it exerts a positive influence over both emissions and sales, as expected. However, Porto results suggest that higher net disposable income lowers emissions with respect to diesel and electrical cars. We conclude that there are evident differences between the two major cities that could mean that in Porto people are more aware of the importance of reducing emissions than in Lisbon and therefore they use higher disposable income to buy less polluting cars.

It is also visible some clear differences between the two cities when we account for the effect of the employment rate. While in Lisbon increases in the employment rate lead to a reduction of emissions with respect to all average cars, in Porto higher employment rates increase emissions for all categories, expect for electrical cars, while decreasing average sales of all cars. This somehow contradictory effect may have been also a result of the recent crisis as Wadud (2014) had already stressed in his study for the UK. We do not account for the crisis effect into estimations but as observed in the data description we may see a clear effect of it, both in terms of emissions and sales of new cars.

*3.2.2.4. Fuel price.* Higher gasoline prices have a positive and significant effect over all cars sales and electrical cars sales. This result is consistent with the change of households' preferences with respect to cars, especially electric ones whose sales increased in the last years. This evolution is due to European laws transposed into national laws benefiting the sales of electric vehicles, less polluting and more environmentally friendly. Our results to the Portuguese case point into the same direction as Wadud (2014). Using a monthly database from 2005 until 2012, the author uses the real diesel price to study its influence over the fuel economy in miles per gallon with the goal to understand the effects of recent policies on new vehicle fuel economy in the UK. The author concludes that both income and the recession had some role in improving the fuel economy, but the effect of fuel prices was relatively small. The author thus recommends the consideration of income effects by policy makers while devising demand side policies. Considering all cars, we observe that a 1% increase in diesel fuel average prices, reduce the average emissions in 0.32% in the short run, which is a positive effect in environmental terms. This result seems to indicate that for the Portuguese case, fuel price increases will have negative effects over sales and emissions.

*3.2.2.5. Population density.* Chen and Chen (2017), studying the coupling of energy and carbon flows associated with cities, conclude in favour of a strong correlation between energy, carbon emissions and population, and also that higher density is not

always associated with lower emissions. They even state that economic performance, industrial structure and technology are more important factors than urban population size. The reasons for the differences in GHG emissions of high-income European cities are also assessed in Calbick and Gunton (2014) considering nine factors: climate, population pressure (growth and density), economic output per capita, technological development, industrial structure, energy prices, environmental governance, pollution abatement and control expenditures, and environmental pricing. Thus, population density seems relevant to be included in estimations as a factor explaining emissions and sales of new cars.

Results in Table 5 show that population density in Portugal has a negative impact on emissions of all new cars sold, as well as over emissions of gasoline and diesel cars. This is not in accordance with Chen and Chen (2017) results, but when accounting for Lisbon and Porto population density our results support those of the authors except in electrical vehicles for Lisbon. Therefore, higher population density in cities seem to increase average emissions of new sold cars. Moreover, there also seems to exist contradictory effects in terms of average sales of new cars when considering population density for the whole country and the effect of population density at the city level. The impact signs are clearly different over sales, being positive for the country, but evidencing a negative relationship between average sales and population density when accounting for major urban areas, calling our attention for the need to consider individual cities effects in both sales and emissions. The fact that higher population density decreases sales of new cars may be justified by the available public transport facilities that exist in the two cities included in this analysis. Both these cities are the only ones in Portugal where there is a subway and a developed transportation network system. The availability of more public transport alternatives may thus contribute to lower the sales of new cars. This does not necessarily mean higher environmental consciousness from individuals that opt for the available public transport alternatives, since this is usually a more inexpensive option when compared to the particular vehicle.

*3.2.2.6. General discussion.* There is still a long "road" to follow regarding transport need changes. Zhao (2017) argues that existing transportation infrastructure and the human nature of satisfying their needs with least effort, favours liquid alternative fuels over electricity or hydrogen. Moreover, Zhao (2017) concludes that the continued supply of oil will reinforce the existent transportation infrastructure, which will continue to make it impossible for electricity or hydrogen based transportation system to compete with current liquid fuel based transportation system economically. Additionally, using a "two-step" approach, Palencia et al. (2017) estimate the optimum market penetration of lightweight and electric-drive vehicles in the long-term and the impact on the light-duty vehicle fleet of Japan. The goal was to estimate the vehicle market composition in 2050. They conclude that fuel cell hybrid electric vehicles dominate when low cost is prioritized and that a shift to battery electric vehicles occurs when low $CO_2$ emissions are prioritized. In the base scenario, $CO_2$ emissions should be reduced 56.9% between 2012 and 2050. As such, there is still a long path way to follow in order to achieve $CO_2$ emission decreases betting over electric-drive vehicles (hybrid, plug-in hybrid, battery, fuel cell and fuel cell hybrid).

Road geometry has also been showed to have a great impact on overall fuel consumption and emissions implying the need for urban road network optimization (Luin et al., 2017). Moreover, the eco-design process of road construction plays a vital role in achieving the effective carbon footprint reduction (Mao et al., 2017). As such, it is also suggested that GHG emissions associated to road construction should be paid more attention, meaning that planning of road network expansion and the choice of road pavement materials should be determined with a strong consideration on their GHG impacts (Chen et al., 2017). As also previously stated, besides legislating cars, policies for other transport sectors and modes are needed to decrease $CO_2$ emissions (Thiel et al., 2016).

Furthermore, the green consumer behaviour will carry greater weight on manager's decisions and, thus, actions that meet the lean and green can be established in a way that both practices can add value to eco-efficiency or greater sustainability to the supply chain (Marcilio et al., 2018) with respect to road vehicles. Additionally, previous results seem to indicate that the most effective strategy to reduce energy consumption and maybe fuel subsidy is through the retirement program of old vehicles. Moreover, new fuel vehicle strategies like introducing compress natural gas vehicle o public transportation appears to give little significance in reducing the annual subsidy costs, fuel consumption and $CO_2$ emissions (Deendarlianto et al., 2017), leaving room for the need of a deeper analysis concerning vehicles and emission reductions in road transport. We believe that only a specific government analysis of their own possibilities, with respect to this topic, will lead to the best options to be undertaken in order to fulfil the country needs.

There is still the need to encourage consumers to buy more environmental-friendly cars. Like other environmental-friendly innovations, the initial excitement displayed by potential consumers does not necessarily translate into actual purchases (Lane and Potter, 2007; Naor et al., 2018). Naor et al. (2018) explore the adoption of a sericitized business model in an entrepreneurial venture to conclude that the service component is a significant factor in the decision to buy an e-car. Using a generic agent-based model, van der Veen et al. (2017) explore policy impacts for servicing in three product-based markets (car and bike sharing, crop protection and domestic water saving systems), concluding that market-level transitions from product-based to service-based production and consumption patterns may help in absolute decoupling (reducing environmental impact, while increasing economic growth). Thus, public policies should also uptake servicing to promote the consumers buying consciousness change.

Wang et al. (2017) conclude that financial benefits, infrastructure readiness, environmental concerns and policy privileges, all have a positive impact over consumers purchasing intention. As for China, a clear understanding of the new vehicles purchasing behaviour in Portugal, considering what the current policy is, and how to answer to its adjustment, are both theoretically and of practical significance for the new energy vehicles industry. What is clear, as for now, is that to turn subsidies more tangibly targeted in Portugal, we need to present manufacturing strategy proposals considering the policies influence, as well as consumers' demand and needs. Only these jointly considerations would be able to explain new cars purchasing patterns and their corresponding emissions impact (and future abatement needs) in Portugal.

## 4. Conclusion

This article uses a completely unexplored database of sales regarding new cars sold in Portugal during the period of 2002 and 2016. The database contains useful information regarding categories, marks, models, car characteristics, fuel used, type of car, engine size, power and sales by month, among others. Using this database we have explored the evolution of average $CO_2$ emissions and sales considering different types of new cars sold (gasoline, diesel and electrical) in terms of descriptive statistics. We have also applied multiple regression models using macroeconomic variables in order to justify changes, both in terms of sales and emissions. Results provide very interesting conclusions and allow inferring

how policy makers should redirect attention when formulating new policies regarding environmental performance.

Environmental consciousness of population is needed because lower emissions or higher sales of electrical vehicles observed may be due to the effect of the introduced laws and not to the individual efforts to decrease global warming. This shows that we may have legislation imposing willingness to achieve the emissions level but not consumers' willingness to achieve it, as desired. This also leaves space for a higher intervention concerning population awareness for emission reduction needs and for the importance of choosing cars that should help achieving the emission reduction targets and consequently global warming reduction effects.

Results demonstrate that including macroeconomic effects, household characteristics and city specificities is important for both emissions and sales behaviour. When long-term interest rates increase, the gasoline car sales decrease. However only in this category, a significant impact was found. Including the population density effect by considering high urban areas in Portugal (Lisbon and Porto), we observe that there is a positive and significant correlation between emissions of new cars sold (for all, gasoline and diesel) and population, leading us to the conclusion that higher concentration of persons increases emissions, by increasing the circulation of vehicles by squared km. As such, accounting for cities specificities allows us to observe different impacts and to consider city characteristics when designing policies regarding $CO_2$ abatement effects associated to new car sales.

Provided the above evidence we realise that when considering effects over average emissions of new cars sold and average sales we need to be aware of the region/city where we are analysing this interactive effects. As evidenced by the results the consideration of different cities in our analysis changed the overall results and evidenced different impacts, in both sign and magnitude. In terms of electrical vehicles, the results are not so straightforward to interpret and seem to point into the direction of all cars sold results. This may be because we have only observed effective sales of this kind of cars from 2010 onwards, since previously they almost did not exist or assumed a value of zero in our sample.

However, taxation benefits in Portugal show a clear positive impact over electrical cars sales, which have increased exponentially since 2010. Once more, this household behavioural change does not necessarily mean higher environmental consciousness of the importance of decreasing $CO_2$ emissions issued, but rather concern about income savings since lower taxes and higher monetary benefits associated to the purchase of these particular vehicles, together with the growth of available car models, justify the behavioural change and sales increase. In this sense, the presented data offer incentives for the public organs to rethink their spur policies with regard to environmental issues.

Consumers have income restrictions and so they prefer to buy an electrical vehicle, especially utilitarian in major cities for daily moves. Since, from December 2014, the green taxation legislation allowed for new incentives for electric and plug-in vehicles, like purchase subsidies and tax reductions, thus increasing disposable income. This may also be an indirect effect of the recent financial crisis, the effects imposed over households' income in order to ensure the recovery. Therefore, more variables related to cities specific effects, households' behaviour and tax laws regarding new car acquisitions are all important to be considered when studying the factors influencing both emissions and sales. Future research should include environmental consciousness of consumers' variables also into the analysis to allow analysing whether purchasing decisions are based mainly on economic factors rather than on the degree of environmental consciousness. As for now, and given data availability, we are not able to take further conclusions.

One possible extension of this work, but not allowed by the current database, is to consider sales by city and try to find possible explanatory variables for both emissions and sales, as our results point for the existence of this differentiated effect. Moreover, we could also analyse the effects over emissions and sales according to different car segments, as the literature also points. . We could take different conclusions in terms of households environmental awareness and "exhibiting effect by having a more powerful new car" even if that implies higher $CO_2$ emissions in the spirit of the conclusions taken by Zachariadis (2013) for the German market. Likewise, a comparison of these effects both for cities in Europe or even among European countries may reveal significant differences and may allow for better European policy design. Some other authors show evidence on different effects for different European countries, but none at the city level or accounting for city specific effects, at the top of our knowledge, mainly due to the lack of reasonable data to perform such analysis.

The results here presented clearly show that although governmental incentive programs are interesting they have failed to produce any respectable results, at least in the Portuguese market and for the initial expected extent for which they have been created for. Future research should also account for other possible interesting concerns to allow clearly understanding the evolution of emissions and the evolving vehicles market. For instance, it would be interesting to analyse the costs of change in technology adoption including infrastructure, vehicle imports, charging portal network, etc. Moreover, to identify who are the stakeholders responsible for all aspects of this change and to allocate responsibility and governance to each of them. The government may be one of these stakeholders, as the results clearly show. Another research question may be how would be the development of local talent pool resulting from new technology adoption. Finally, we may in the future also to account for supply and demand aspects for these changes.[5]

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